RESEARCH HIGHLIGHT
Basic Sciences Program
Geosciences Subprogram

Project: Upscaling experiments conducted on a block of volcanic tuff: Results for a bimodal permeability distribution

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Objectives: Here we employ a specially adapted minipermeameter test system to physically investigate permeability upscaling on a block of volcanic tuff. Key to this investigation is the bimodal (i.e., non-Gaussian) permeability distribution exhibited by the tuff sample.

Results: Over 31,000 permeability measurements corresponding to five different sample supports (i.e., sample volumes) were collected from a meter-scale block of tuff. Results show that the measured spatial permeability patterns, bimodal permeability distribution, and semivariogram structure/length scales are closely related to the strong textural contrast characterizing the tuff sample (i.e., highly porous pumice fragments embedded in a tight rock matrix). Each of the summary statistics show distinct and consistent trends with increasing sample support (i.e., upscaling). As the sample support increases the mean and variance decrease according to a power law relation, the semivariogram range increases linearly, while the general structure of the semivariogram (isotropic, spherical model) remains unchanged. Interpretation of the ensemble mean upscaling is explored through comparisons drawn with classical effective media theory, while analysis of the local (i.e., limited neighborhood about each sampling point) upscaling is accomplished with a novel conditional expected value model developed in this paper.

Significance: Local analysis of the acquired data reveals strong variability in permeability upscaling from point to point throughout the sampling domain. Specifically, the permeability upscaling exhibited by zones rich in pumice is very different from zones dominated by matrix, unless the averaging volume is significantly larger than the spatial correlation scale. Also, we find the general upscaling trends exhibited by the ensemble statistics are consistent with the basic concepts of volume averaging, albeit non-linear volume averaging. The bimodal characteristics of the tuff sample and the non-uniform flow conditions imparted by the minipermeameter contribute to the non-linearity.

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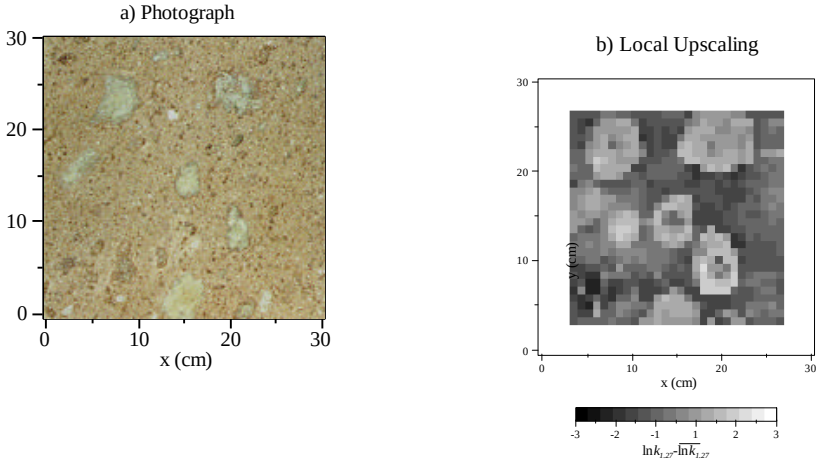

Figure: a) photograph of the sampled tuff block, and b) two-dimensional map showing the difference in permeability upscaling between zones rich in pumice (positive values, which indicate an increasing trend in permeability) versus those dominated by matrix (negative values or a decreasing trend in permeability).